FLUID PHYSICS BRANCH

RESEARCH DIVISION

OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY

FIFTH INTERCENTER AND CONTRACTORS CONFERENCE ON PLASMA PHYSICS

Part I Program and Introduction

WASHINGTON, D. C.

MAY 24 – [illegible]

FIFTH NASA INTERCENTER AND CONTRACTORS CONFERENCE
ON PLASMA PHYSICS

Room 62012, FOB-6
400 Maryland Ave., S. W.
Washington, D. C.

May 24 - 26, 1966

AGENDA

Tuesday Morning, 24 May 1966

8:30-9:00 a.m. Welcome Address — A. Gessow, NASA Hqs.

Introduction — K. Thom, NASA Hqs.

9:00 a.m.-1:00 p.m. Presentation of Plasma Research at Langley Research Center
Chairman: D. Bartz, Jet Propulsion Laboratory, Pasadena, California

A. Review of Langley Research Program on Linear Crossed-Field Plasma Accelerators and Electric Forces on Satellites
G. P. Wood, Head Magnetohydrodynamics Section,
NASA Langley Research Center, Hampton, Virginia

1. Results of Diagnostics of the Flow from the 1-Inch Plasma Accelerator
W. R. Weaver, A. F. Carter, D. R. McFarland and G. P. Wood

2. Status Report on 20-MW Linear Plasma Accelerator Facility
A. F. Carter, G. P. Wood, W. R. Weaver, D. R. McFarland and S. K. Park

3. The Thermodynamic Properties of Seeded Nitrogen
S. K. Park

4. Electric Drag and Torques on Satellites
F. Hohl and G. P. Wood

B. Review of Langley Research Program in Plasma Spectroscopy and Plasma Guns
G. K. Oertel
NASA Langley Research Center, Hampton, Virginia

1. Magnetic Compression Experiment
   G. K. Oertel, J. Norwood and M. D. Williams

2. A Preliminary Study of Field Non-uniformity in a Long
   Theta Pinch Coil
   J. Norwood

3. A Minimum-B Type Coil
   W. A. Cilliers

4. New Jitter Measuring Technique and Application to
   Spark Gap Studies
   M. D. Williams

5. Semi Corona Ionization Equations
   G. K. Oertel

6. Results of a Spectroscopic Study of Preheater Plasma
   L. P. Shomo and G. K. Oertel

7. Measurements of Stark Widths of Argon Lines in a T-Tube Plasma
   N. Jalufka and G. K. Oertel

8. The Effect of Viscous Drag on the Performance of a
   Coaxial Plasma Gun
   J. Norwood

9. The Production and Propagation of Plasmoids in a
   Non-Linear Alfven Wave
   J. Norwood

C. Experiment and Theory of the MPD Arc
   R. V. Hess
   NASA Langley Research Center, Hampton, Virginia

1. Parametric Study of MPD Arc at Low Exhaust Pressures
   (1u to 1/10uHg)
   P. Brockman, R. V. Hess, J. Burlock and D. Brooks

2. Effect of Mass Injection on Voltage Distribution in Hollow Cathode
   Accelerator
   J. Hoell, D. Brooks and R. Weinstein

3. Analysis of Acceleration Mechanisms and Ionization in MPD Arc
   B. Sidney, R. V. Hess and P. Brockman

4. Development of Mass-Flow Meter and Injection Through Electrodes for Lithium MPD Arc
   O. Jarrett

5. Resistive Instabilities for Plasmas in Crossed Electric and Magnetic Fields
   R. Varma

D. Diagnostics for High-Power, Low-Density, Steady Plasma Streams
   P. Brockman
   NASA Langley Research Center, Hampton, Virginia

1. Langmuir Probe Techniques for Measurements of Electron Temperature Distributions in High Energy, Low Density Plasma Streams
   D. Brooks and J. Hoell

2. Optical Measurements of Temperature and Velocity in Low Density Plasma Streams
   F. Bowen, G. Oertel, R. V. Hess, N. Jalufka and J. Burlock

3. Microwave Measurements of Plasma Density Fluctuations
   J. Burlock and T. Collier

E. Review of Langley Theoretical Research on Collisionless Plasmas
   M. R. Feix
   NASA Langley Research Center, Hampton, Virginia

1. Forced Oscillations in Collisional Plasmas and Rarefied Gases
   G. Massel and M. Feix

2. Computer Simulation of Collisionless One-Dimensional Plasmas
   R. Weinstein and M. Feix

3. Linear and Non-Linear Treatments of the Vlasov Equation by Means of a Fourier-Hermite Transformation
   F. C. Grant and M. R. Feix

4. Nonhomogeneous Plasma Kinetic Theory
   L. D. Staton and M. R. Feix

5. A One-Dimensional Plasma Model for a Self-Gravitating Star System
   F. Hohl and M. R. Feix

F. Review of Langley Research Program on Reentry-Flight Plasmas
P. W. Huber
NASA Langley Research Center, Hampton, Virginia

1. Determination of Reentry Plasma Properties from Interpretation of Manned Spacecraft Flight Data
P. W. Huber

2. Evaluation of Reentry Air Chemical-Kinetics Using Instrumented Flight Probes
J. S. Evans and C. J. Schexnayder

3. Impedance and RF Propagation from Dielectric and Plasma Covered Apertures
C. T. Swift

G. Barium Release Experiment
D. Adamson
NASA Langley Research Center, Hampton, Virginia

(with R. E. Davidson and other Langley Staff)

H. Non-Equilibrium Properties of Plasmas
W. E. Meador
NASA Langley Research Center, Hampton, Virginia

1. Thermal Properties of Plasmas (Reaction Conductivity, etc.)

2. Electrical Resistivity of Plasmas (Complete First-Order Theory)

3. Evaluation of Transport Coefficients by the Balescu Equation

(with C. Fricke)

<u>Tuesday afternoon, 24 May 1966</u>

2:00-3:00 p.m. <u>Panel on Plasma Turbulence</u>
Moderator: A. Busemann, Univ. of Colorado
N. Rostocker, General Atomic
O. Mawardi, Case Institute of Technology
C. Tchen, National Bureau of Standards
R. Hess, Langley Research Center
Secretary: J. Norwood, Jr., Langley Research Center

3:00-5:00 p.m. <u>Presentation of Plasma Research at Jet Propulsion Laboratory</u>
Chairman: W. Rayle, NASA Lewis Research Center, Cleveland, Ohio

1. Comparison of Experimental with Predicted Convective Heat Transfer from a Laminar Boundary Layer of Thermally Ionized Argon
Dr. Lloyd H. Back

2. Behavior of a Magnetic Neutral Line in a Plasma
Dr. Alexander Bratenahl

3. Laser Induced Breakdown, Electron Recombination and Shock Wave Structure in Partially Ionized Gases
Dr. Che Jen Chen

4. Measurements Near a Shock Wave in a Seeded Gas Plasma
Dr. Walter Christiansen

5. High Purity Shock Tube Ionization Studies
Dr. Arnold J. Kelly

6. Heat Transfer from Steady Internal Flows of a Thermally Ionized Gas - Core Flow Analysis
Paul F. Massier

7. Magneto-fluid Dynamic Flow over Bluff Bodies
Dr. Tony Maxworthy

8. Measurement of Electron Temperature and Density Profiles in an MPD Arc
Dr. Noble M. Nerheim

9. Study of a Nonequilibrium MHD Generator Utilizing Inert Gases and Inert Gas Mixtures
Gary R. Russell

10. Research in Plasmas in Thermionic Diodes
Katsunori Shimada

11. Kinetic Theory Studies of Fundamental Plasma Problems
Dr. Ching-Sheng Wu

Wednesday Morning, 25 May 1966

8:30 a.m.-12:30 p.m. Presentation of Plasma Research at Lewis Research Center
Chairman: H. Stine, NASA Ames Research Center, Mountain View, California

1. Generating a Hot-Ion, Magnetically Confined Plasma With a Modified Penning Discharge
J. R. Roth

2. Harmonic Response of Forced Non-Linear Plasma Waves
R. R. Woollett

3. R. F. Power Transfer to Ion Cyclotron Waves
D. R. Sigman and J. J. Reinmann

4. Electron Impact Cross Section for Atomic and Molecular Hydrogen Calculated by Gryzinski's Classical Theory
G. M. Prok, C. F. Monnin, and H. J. Hettel

5. Preliminary Measurement of Plasma Fluctuation in a Hall Current Accelerator
J. S. Serafinni

6. Effect of Magnetic Beach on R.F. Power Absorption in Ion Cyclotron Resonance
C. C. Swett

7. The Possibility of Anomolous Cathode Emission Due to Ion Induced Tunneling
J. E. Heighway

8. Consideration of Irreversible Thermo-Dynamics as an Approach to a MHD Plasma Problem
N. Stankiewicz

9. Status of Large Vacuum Facility H_2, NH_3, Li MPD arc Test
D. J. Connolly, R. E. Jones, S. Domitz, and G. R. Seikel

10. Performance, Endurance, and Diagnostics of Magnetic Expansion Thrustor
D. N. Bowditch, A. E. Johansen

11. R.F. Induction Heating and Production of Plasma At Low Pressures
R. J. Sovie, G. R. Seikel

12. Comparison of Theory and Experiment for Traveling Magnetic Waves in Plasma Accelerator
R. W. Palmer, G. R. Seikel

13. Volume Ion Production Cost in Tenuous Plasmas
R. J. Sovie, J. V. Dugan, Jr.

14. Charged Particle Transport by Monte Carlo Analysis
C. M. Goldstein

15. Solution of Boltzmann and Rate Equations for Nonequilibrium MHD Plasma
F. A. Lyman, J. V. Dugan, Jr., L. U. Albers

16. Calculations of Three-Body Collisional Recombination Coefficient for Cesium and Argon Atomic Ions With an Assessment of the Gryzinski Cross Sections
J. V. Dugan, Jr.

Wednesday Afternoon, 25 May 1966

1:30-2:30 p.m. Panel on Non-Equilibrium Ionization
Moderator: J. Kerrebrock, Mass. Inst. of Technology
H. Hassan, North Carolina State University
G. Russel, Jet Propulsion Laboratory
F. Lyman, NASA Lewis Research Center
W. Maedor, NASA Langley Research Center
Secretary: J. Heighway, NASA Lewis Research Center

2:30-5:00 p.m. Presentation of Plasma Research at Ames Research Center
Chairman: M. Ellis, NASA Langley Research Center

1. Magnetic Compression Waves in Collisionless Plasmas - Oblique Ambient Magnetic Field
V. J. Rossow

2. Coil Systems for Measuring Conductivity and Velocity of Plasma Streams
V. J. Rossow

3. Ablation Products Radiation
   W. Winovich

4. Effects of Turbulence in Constricted Arc Plasma Generators
   V. R. Watson

5. Behavior of Faraday Cups in Plasma Beams
   W. C. Pitts and E. D. Knechtel

6. Flow-Swallowing Enthalpy Probes
   L. Anderson and R. Sheldahl

7. Constricted Arc Performance Status
   J. W. Vorreiter

8. Ionic Recombination Rate of Dissociated Nitrogen
   C. Park

9. Investigation of Transport Phenomena in the Physics Branch
   W. F. Ahtye

10. Electrode Phenomena in High Energy Densith Discharges
    H. R. Poppa

11. Stagnation Point Electrodes
    M. Chen, Yale University

12. High Pressure Cathodes
    A. Tucheman, AVCO

13. Electron Energy Loss Factors
    S. T. Demetriades, STD Research Corp.

14. Plasma Flow Around the Quiet Magnetosphere
    J. R. Spreiter

15. Results of the Pioneer VI Ames Plasma Probe Experiments
    J. H. Wolfe

Thursday Morning, 26 May 1966

8:30-9:15 a.m. Presentation of Plasma Physics Research under OSSA Physics and Astronomy Programs
Chairman: J. Spreiter, NASA Ames Research Center

1. Experimental and Theoretical Investigation on Selected Aspects of Plasma Turbulence
I. Bernstein, Yale University

2. Plasma Physics Research at the University of Maryland
D. Tidman, University of Maryland

3. Summary of Plasma Research under OSSA Physics and Astronomy Programs
A. Opp, NASA Hqs.

9:15a.m.-12:30 p.m. Presentation of OART-RRP Contractors Plasma Research
Chairman: V. Rossow, NASA Ames Research Center

1. Stability of Plane Magnetohydrodynamic Channel Flow with Parallel Magnetic Field
P. Nachtsheim, NASA Lewis Research Center and
E. Reshotko, Case Institute of Technology

2. Magnetohydrodynamic Boundary Layers Involving Non-Equilibrium Ionization
A. Sherman, General Electric, King of Prussia, and
E. Reshotko, Case Institute of Technology

3. Plasma Boundaries
J. Fay, Massachusetts Institute of Technology

4. Electrode Effects in Accelerators
S. Aisenberg, P. Hu, V. Rohatgi and S. Ziering, Space Science Inc.

5. Magneto aerodynamic Drag and Shock Stand-Off Distance
C. Chang, R. Nowak, S. Kranc, R. Porter, G. Trezek, M. Yuen, T. Anderson, and A. Cambel, Northwestern University

6. Properties of a Magnetically Suspended Arc in Supersonic Flow
A. Kuethe, University of Michigan

7. A Critical Mass Flow Model for the MPD Arc Jet
H. Hassan, North Carolina State University

8. Analysis of Instabilities in a Linear Hall Current Accelerator
G. W. Garrison, Jr., and H. A. Hassan, North Carolina State University

9. Experimental Investigations of Strong Shock Waves Moving Through an Ionized Gas
G. L. Spencer, Case Institute of Technology

10. Harmonic Generation in a Microwave Plasma
F. J. Mayer and O. K. Mawardi, Case Institute of Technology

11. A Wide-Band Dicke Type Radiometer
A. T. Alper and O. K. Mawardi
Case Institute of Technology

12. Experimental Study of the Interaction of Energetic Electron and a Plasma
W. B. Johnson and M. R. Smith, Case Institute of Technology

13. A Beat Frequency Interferometer For Plasma Diagnostics
W. B. Johnson, A. B. Larsen, and T. P. Sosnowski, Case Institute of Technology

14. Turbulence in a Rarefied Plasma
C. Tchen, National Bureau of Standards, Washington

15. Plasma Vortices and their Motion in Inhomogeneous Magnetic Fields
W. Bostick, Stevens Institute of Technology

16. Experimental Investigations of the Fundamental Modes of a Collisionless Plasma
J. Malmberg, General Atomic

17. Plasma Radiation and the Detection of Non-Maxwellian Velocity Distributions
J. Noon, P. Blaszuk and E. Holt, Rensselaer Institute of Technology

18. Modes of the Kadomtsev Instability
D. Huchital and E. Holt, Rensselaer Inst. of Tech.

19. Stability of Plasmas Subject to Convective Instabilities
E. Holt and D. Hutchital, Rensselaer Inst. of Tech.

20. Plasma Measurements from 3 to 120
Kilobars of Pressure
J. Robinson, University of Michigan

21. Investigations on the Mechanism of the Material
Release in the High Vacuum Breakdown
R. Schneider, University of Florida

22. Synthesis and Characterization of Magneto Fluids
R. Rosensweig, Avco RAD

23. A - C Travelling Wave-Plasma Stream
Interactions
M. Lessen, The Univ. of Rochester, N. Y.

Thursday Afternoon, 26 May 1966

1:30-2:30 p.m. Panel on Plasma Surface Interaction
Moderator: J. Fay, MIT
E. Reshotko, Case Institute of Techn.
L. Nichols, NASA Lewis Research Center
W. P. Wood, NASA Langley Research Center
S. Ziering, Space Science Inc.
Secretary: S. Aisenberg, Space Science Inc.

2:30-5:30 p.m. Presentation of Plasma Research under
OART - RRE and OART - RNT Programs
Chairman: G. Seikel, NASA Lewis Research Center

1. Propagation and Dispersion of Hydromagnetic and
Ion Cyclotron Waves in Plasmas Immersed in
Magnetic Fields
A. A. Dougal, The University of Texas

2. A - C Power Generation Through
Wave-Type Interactions
G. L. Wilson, MIT

3. Anode Oscillations in Cesium Plasmas
H. S. Robertson, University of Miami

4. Transverse Stream Instabilities in Plasmas
W. Bennet, North Carolina State University

5. Pulsed Plasma Propulsion
R. G. Jahn and W. von Jaskowsky, Princeton Univ.

6. Pulsed Plasma Accelerator
P. Gloersen, B. Gorowitz, and T. W. Karras
GE Space Sciences Lab.

7. Coaxial Plasma Gun
A. V. Larson, L. Liebing, A. R. Miller, and
R. Dethlefsen
Space Science Lab., General Dynamics Convair

8. Diagnostics of Accelerating Plasma
C. C. Chang, T. N. Lie and A. W. Ali,
The Catholic University of America

9. MPD Arc Jet Thrustor Research
R. R. John and S. Bennet
Avco, Space Systems Division

10. Permanent Magnets For MPD Arc Thrusters
A. C. Eckert and D. B. Miller
G. E. Space Sciences Lab., King of Prussia, Pa.

11. Electron Cyclotron Resonance Plasma
Thrustor Development
D. B. Miller, A. C. Eckert and C. S. Cook
G. E. Space Sciences Lab., King of Prussia, Pa.

12. Hall Current ACCELERATOR
G. L. Cann, P. F. Jacobs
Electro Optical Systems, Inc.

13. MPD Thruster Research
A. Ducati, Giannini Scientific Inc., St. Anna, Calif.

14. Investigation of Plasma Resonance Phenomena
S. J. Tetenbaum, Lockheed Research Labs.
Palo Alto, California

WELCOME ADDRESS

by

Alfred Gessow
Chief, Fluid Physics Branch

If you look at the first item on the agenda, you will see it is called "Welcome Address." Don't be alarmed at the imposing title. My remarks won't take very long and will just serve two purposes -- the first to indeed welcome you to this Fifth Intercenter and Contractors Conference on Plasma Physics, and second to allow people to get settled into their seats before the real business of the meeting begins.

Let me say a few words about who is here and what our purposes are in having this conference. Represented on the agenda, and present in this auditorium during these three days, are the bulk of the investigators who are doing research and development in the area of plasma physics and MHD under NASA sponsorship. Thus, work going on in-house and under grants and contracts with universities, non-profits, and industry are represented. These efforts are funded by various Headquarters offices, in addition to our own, and therefore represent a spectrum of activity ranging from basic, seemingly non-oriented, studies to applied R and D on specific devices.

I would like to point out that the purposes of this meeting are different from technical society meetings that are held outside of NASA, and in some respects, different from other meetings that our Branch sponsors in other areas of fluid physics. In outside technical meetings, papers are given (supposedly) on projects which have progressed to the point wherein significant results can be reported. Our purpose is to get reports on plans and progress, as well as results, from on-going projects. These oral reports provide the opportunity for each man to become -- if not familiar -- at least aware of what work is carried on by NASA and who is doing it. Such coordination is very necessary in an organization as complex and widespread as ours.

I refer not only to administrative coordination, but technical as well. By describing his work before his fellow researchers at a meeting such as this, the researcher has the benefit of constructive criticism which may give him a lead on solving a problem, or might even cause him to take a different tack altogether. He hopefully would get the same benefits by

listening to the other presentations and comments. We think that this kind of exposure is particularly good for the junior researcher who may not ordinarily get to deliver a paper, or even attend, a technical society meeting.

I feel that I must apologize for, or at least explain, the formidably lengthy agenda. Actually, it is partially the result of tradition. Our first plasma physics meeting of this type was held approximately 10 years ago while we were still the NACA. The number of in-house projects was much smaller than we have today, of course, and the number of outside projects was almost nil. The subsequent expansion of research, both in-house and by grant and contract, was great and consequently we end up with the program that we have today. I might add that in our other fluid physics areas we limit the program to the out-of-house activities, with attendance and discussion by in-house personnel. Although this latter format results in a less crowded agenda, there are obvious advantages in presenting the entire program.

Note that the agenda is broken down into groups of presentations by each in-house unit, by contractor units, etc., rather than be subject matter. We arranged it that way primarily in order to "fix an image," so to speak, of the work done by different groups and in order to help identify in the mind of the audience as to where a particular piece of work is being done. It also enables one man to report on the work of several people when time limitations or travel restrictions prevent a researcher from presenting his own material.

In addition to reports on individual projects, the program contains three roundtable discussions on topics of current interest to the plasma field. We feel that such discussions are both stimulating and also serve to help chart future research.

The proceedings of this conference are summarized in the form of research abstracts which you have submitted. We feel that these abstracts will form a valuable record of the conference, in that they present the objectives, background, and status of each piece of work, as well as, in many cases, significant research results. They are bound in four separate volumes, in addition to an agenda "volume," simply for ease of handling.

A final word about the schedule. The talks and the meeting itself will be informal, and needless to say we welcome comments

and provocative questions -- the more the better. In view of the very tight schedule, however, such discussions must be brief and to the point. I ask the cooperation of the speakers and session chairman to adhere strictly to the allotted time so that each speaker will have his opportunity to be heard.

I'll now turn this meeting over to Dr. Thom, who is the general chairman for this meeting and who has worked hard on getting the meeting organized.

PLASMA RESEARCH

Stepping Stone To Future Space Technology

by

Karlheinz Thom
Fluid Physics Branch

A couple of months ago, at the Fourth Goddard Memorial Symposium, a number of illustrious speakers from universities, industry, and government drew pictures of the Space Age in the Fiscal Year 2001. Such projections were, of course, highly speculative, and the conservative participant may have looked at them with lots of reservation. Also, one was inclined to judge that the Fiscal Year 1986 might have been a better target for such scientific and technological forecasts. Twenty years are a reasonable time for correlating such forecast with the lead times for developing advanced technological systems. Thus, predicting the technological needs in FY 1986 would have had implications to setting goals for present research and development program planning. The detachment from such possible implications, however, enabled the speakers to treat more liberally the subject of scientific and technological forecasting.

The technical man is traditionally restrained regarding prognoses in his field, so that in retrospect the achievements of the recent decades exceed by far the expert spectulations in the past. If an extrapolation into the future by analogy with the past is assumed to be valid, one should consider even optimistic, contemporary predictions, as conservative. The consensus of the Symposium was then, after discussing pros and cons, that in the picture, about the turn of the millenium, we will be in the position to do, technologically, almost everything, -- apart from doing ridiculous things, such, for instance, as exceeding the velocity of light, or operating the perpetium mobile. Controversy remained only regarding the question: what should we do? Or, which of all the technological options, emerging from our rapidly growing sciences, will we pick up and promote?

Even if the US GNP, as predicted, keeps growing at rates comparable with those in the past, so that in the year 2000 our national income will exceed 3000 billion dollars, and even if the Federal Government budget will remain at 20% of the GNP, as it appears to be necessary to many experts for the stabilization of the economy as a whole, will space spending remain at roughly 5% of the government expenditures? In one of the more conservative presentations at the Symposium, it was pointed out that too many things remain to be done right here on the earth as opposed to forecasting too brilliant a future of the space program. It was said that technological progress was generally greatly overestimated. For instance,

regarding vital items such as the water closet and the automobile, there was no progress during the past three decades whatsoever!

On the more serious side it was mentioned that problems such as air pollution, water pollution, desalinization of seawater, sociological problems following automation, etc. would rapidly attain priority over the space program, which, after losing momentum in the cold war, would eventually stagnate at a relatively low level. The majority of the speakers however, came to a much more optimistic conclusion. Their arguments regarding the likelihood of an appreciable growth of space technology had, as it appeared to me, a particular bearing to our plasma research, and I think it should therefore be worthwhile to convey some of such thoughts to you. The links to our specific plasma research are, of course, my own contemplations.

Following the illustrious space philosophers, I will first point out that space might be a pioneer-land with a variety of commercial opportunities. (I do not know anything about military utilization of space, neither had this item been discussed at the symposium). Next I will indicate that the economics of commercial use of space heavily depend on advanced space systems, particularly in regard to high energy density propulsion. The development of such "compact" space systems will ultimately enable the smaller nations to participate in the commercial exploitation of space. A worldwide international competition will then be established. I will speculate then that plasma physics research represents a crucial stepping stone toward the development of compact high energy density space systems. The question, whether space technology will be among the prior technological options we will pick in the future, will then be answered through the expectation of space commerce, and the need for technological leadership in international competition. Regarding our virtually unlimited technological capabilities for succeeding so, it will be seen that plasma physics must be expected to contribute an integral part to it.

Following E. P. Wheaton (reference 2), one may define commerce as the selling of goods or services, hopefully for a profit. We introduce the term "entrepreneur," and define it that one who plans and carries out commerce. According to Wheaton, good entrepreneuring involves not only financial and political know how, but also a flair for technology. The work flair is used in the sense of a good instinct for guessing with reasonable accuracy what will come ("in spite of informed technical opinions to the contrary"), sensing its salability, and moving in before those of fainter heart perceive the opportunity.

The term entrepreneur is traditionally connected with private enterprise. However, in the modern world of global-wide communication, problems of internation payment balances, and technological systems, which can be developed only on national basis, one should include also entire Nations in the category of modern entrepreneuring. The question is then, is there something in space that can be sold, and can we expect that a market for space products will exist, so that, apart from such space products, also a demand for space systems will emerge?

The commercial usefulness of satellites for communication is already being demonstrated today. In figures 1 and 2 is shown the possible usefulness of space for global sightseeing and snob appeal for tourists. Based on the assumption that advanced space technology will develop, such as reusable nuclear powered space ships, first the cost for a stay in an orbiting space resort hotel are computed. Both tables originate from different authors (references 1 and 2), and the specific technological means assumed for such computations differ too. But both come to a surprisingly close result. The cost for a one or two day stay in the orbit resort hotel, including transportation up and return, should not cost more than a today's first class round trip ticket to Europe. Considering that presumably the earning capacity of average people will double by the time when such trips become available the journey into orbit appears to be cheap enough that, indeed, millions could afford it. Whether they will go, we do not know. The Russians, as has been told, are selling already reservations for similar trips, and if such information is correct, several thousand individuals have already registered. The more extended space trips, as shown in figure 2, are figured on the basis that a nuclear gaseous core rocket has been developed and that the heavy development cost and initial operational outlays for the vehicle would be written off by government financing. Account has been taken of the vehicle volume limitations, allowing 100 ft^3 per passenger to Earth orbit, 400 ft^3 per passenger to the Moon, and 1000 ft^3 per passenger to the near planets.

Another area of commercial use of space could be the production of materials. In figure 3 (reference 2) is shown a survey of current Earth markets for metals and minerals that are expensive. Nine of the materials cost more than $100 per pound and have yearly markets over $10 million. The yearly markets for uranium and gold are each over $1 billion. Included are some items that might profitably be processed in space, even if not found there. Silicon monocrystals, widely used in electronic manufacture, cost $595 per pound; several of the high-priced metals in extremely pure form are similarly expensive.

Hence, carrying impure metals to orbit for vacuum refinement could easily be profitable. The crucial criterion appears to be the transportation cost.

In figure 4 (reference 3) the cost in dollars per pound useful payload are plotted against velocity increment needed for various space missions. Again reusable space ships are assumed. It is seen that chemical systems at a specific impulse of 425 sec. always will be extremely expensive for trips beyond the Earth orbit because of payload limitation. Nuclear propulsion at 1000 sec. Isp is expected to become quite economical up to lunar missions. For voyages to the planets and astroids only nuclear gas core rockets and nuclear electric rockets will yield economical cargo cost.

In the light of such an analysis of potential cargo cost in space transportation, the previous survey of markets of expensive materials becomes more meaningful. Apparently, multibillion dollar industries and trades could be revolutionized by economical space transport through advanced high energy density systems! For instance, if iron meteorites do represent material from the core of a planet that supposedly broke up some time ago into the astroid belt, an iron asteroid one mile in diameter containing 9% nickel (typical of meteorite percentages) would supply the current world product rate for over 4,000 years! Quite interesting are also speculations regarding the production of rocket fuel on the moon. Because of the low gravitation on the lunar surface, moon made fuels are essentially highly energetic in comparison to Earth produced fuel. This fact may greatly compensate for higher production cost per pound.

It is impossible to list here all the commercial opportunities space may offer, once transportation cost can be reduced in a fashion as outlined before. Reality will probably exceed by far all one can figure and speculate today. The Spanish conquistadores, who conquered the New World five hundred years ago, did not expect much more than gold, -- and what opportunities did actually develop!

It appears to be quite logical to postulate that eventually all industrialized nations should become vitally interested in the exploration and exploitation of space! At the present the smaller nations seem to be discouraged, however, because they see only the monstrous chemical rockets of contemporary space thechnolgy and the enormous size of supporting systems. This

is indicated in figure 5 where the dashed line indicates the ceiling in spending a nation can afford as a reasonable fraction of its gross national product. Surprisingly, many Europeans believe that China eventually will develop large rocket capabilities, because there are plenty of people in China and sufficient resources. Such calculations are based on somewhat old-fashioned methods by which the potential industrial power of a country is estimated by factors such as labor force, energy production and steel production. Modern technology involves more than that; however, for brevity I will not argue but leave China as a tentative partner in the club of large rocket owners.

If technology would remain at the present level and if productivity would not increase, there would be indeed little hope for smaller nations to participate on their own in the conquest of space. We must expect, however, that technology will rapidly develop to more compact systems involving higher energy density operation. In consequence the cost for operating such systems will sufficiently decrease so that in the time of advanced space technology almost every industrialized nation can afford a program of space exploitation, with the result of serious international competition.

Estimates and speculations regarding such advanced compact space technology are manifold in this country. Hard facts, however, are already being demonstrated in the field of electronics, as shown in figure 6. If today a microelectronic thin film device in the size of a dime can substitute a transistor circuit in size of a cigarette box which, in turn, did substitute a shoe box full of tubes and other clumsy gadgets of "modern" electronics only ten years ago, one might reasonably well expect a similar condensation of other technological functions!

In space-flight one cannot get around the physical necessity of accelerating space ship and cargo up to a speed in the order of the escape velocity. This is equivalent with imparting an energy of 100 megajoules to each kilogram of space ship and cargo. In figure 7 we have correlated such energies in terms of temperature with various characteristic speeds of technology. What one might call conventional technology falls in a regime terminated by the velocity of sound in this chart. Corresponding temperatures are that of water vapor and flames. Space technology, characterized by the escape velocity, involves energies, which, if randomized, will turn each matter into a plasma. In the case of reentry we managed to kill that amount of energy by disloading

it to the atmosphere, and we produced that energy for a few hundred kilograms of payload, by burning hundred of tons of chemicals in a near plasma state thermodynamical cycle.

Advances in space technology regarding increasing compactness and higher efficiency in terms of larger payload fractions, very clearly depend then on the mastery of handling higher energy density working fluids, - which are plasmas!

The relations between such higher efficiency, that is greater specific impulse, and time of acceleration, that is the power or power density, respectively, is shown in figure 8 (reference 4). It is seen in this chart that systems which possibly could meet the requirements of high specific impulse and compactness involve working fluids in the plasma state, and in some of the most promising schemes, such as the nuclear gas core rockets, the plasma physics involved appear to be the crucial part in technological feasibility determination; and plasma technology may well become the heart piece of actual system development!

I think we could formulate a number of basic plasma research tasks in support of high energy density plasma space systems, independent of any of the various itemized proposed advanced rocket schemes. However, I will not elaborate on this. How in detail future space systems will look is almost impossible to forsee, but as long as any of them will involve thermodynamics, it will involve plasmas!

We may conclude then, that plasma research constitutes a crucial stepping stone to future space technology, and after the foregoing considerations regarding the commercial conquest of space and the likelihood of an international competition, we might also conclude that this future space technology indeed will come! What the plasma physics requirements then will be we do not know yet to the detail. The best we can do at this time is to learn as much as possible about the plasma, not only regarding plasma technology but also in regard to space environment, in various regimes of density, with and without the various boundary conditions!

By trying to put this meeting together, particularly when looking through the collection of your abstracts, I got the impression that we have done a good job so far. The predominant usefulness of our plasma research is still far ahead in the future, but certain, in my opinion. Others, however, who are more concerned with the needs of the present are naturally less enthusiastic and if they once in a while fail to praise our work, lets do it ourselves!

Thank you!

REFERENCES

1. "Space Propulsion in the Fiscal Year 2001," W. A. Kuhrt, Director of Research, United Aircraft Research Laboratories AAS Fourth Goddard Memorial Symposium, March 1966.

2. "Space Commerce," E. P. Wheaton, Vice President, Research and Development, Lockheed Missiles and Space Company, AAS Fourth Goddard Memorial Symposium, March 1966

3. "Space Transportation," M. W. Hunter, II, Flight Systems Division, Bellcomm, Inc., Los Alamos Scientific Laboratory, Proceedings of an Advanced Nuclear Propulsion Symposium, 1965.

4. "Nuclear Propulsion Schemes Using Magnetohydrodynamic Conversion Techniques," R. J. Rosa and T. R. Brogan, Avco-Everett Research Laboratory; Los Alamos Scientific Laboratory, Proceedings of An Advanced Nuclear Propulsion Symposium, 1965.

COST OF RESORT HOTEL ON ORBIT

COST BREAKDOWN	HIGH INITIAL COST	LOW INITIAL COST	LOW INITIAL COST*
COST OF INITIAL EQUIPMENT ($/LB)	500	100	100
INITIAL INVESTMENT PER PERSON ($)	5,000,000	1,000,000	1,000,000
COST PER PERSON PER DAY ($)	685	157	235
INCLUDING LIFE-SUPPORT SUPPLIES ($)	705	177	255
PERSONAL TRANSPORT COST ($)	600	600	600
TOTAL COST–2-DAY STAY ($)	2,010	954	1,110
2-WEEK STAY ($)	10,300	3,078	4,160

*WITH REPAYMENT OF INITIAL LOAN FINANCED AT 6% INTEREST.

ASSUMPTIONS:

INITIAL EQUIPMENT WEIGHT = 10,000 LB PER PERSON.

LIFE-SUPPORT SUPPLIES = 10 LB PER PERSON PER DAY.

PERSONNEL + BAGGAGE + TRANSFER GEAR = 300 LB PER PERSON.

ORBITAL TRANSPORT TOTAL OPERATING COST = $2 PER LB OF CARGO OR PASSENGERS.

Fig. 1

FY 2001 space tourist information.

DESTINATION	ROUND–TRIP TICKET COST	PASSENGERS PER TRIP	TOTAL TRIP TIME
EARTH ORBIT	$ 1,250	200	24 HR
LUNAR SURFACE	10,000	35	6 DAYS
VENUS	32,000	20	18 MONTHS
MARS	35,000	20	24 MONTHS
MARS EXPRESS	70,000	20	11 MONTHS

Fig. 2

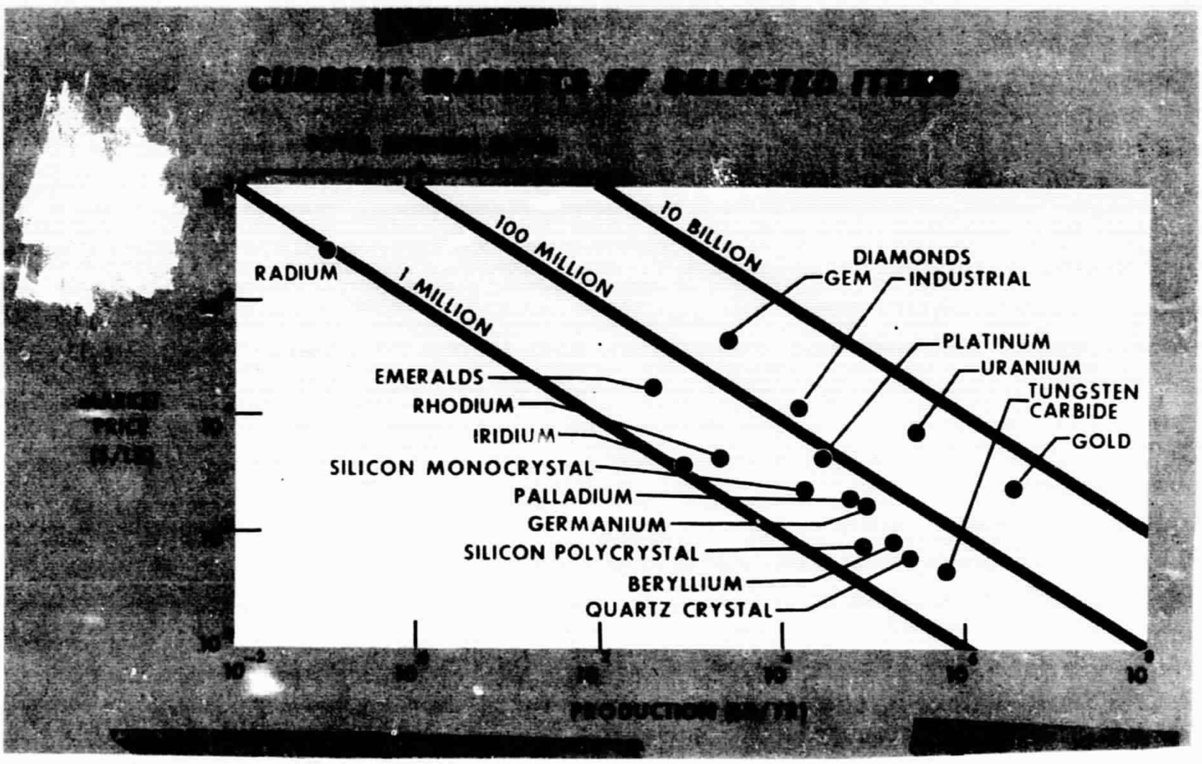

RADIUM
1 MILLION
100 MILLION
10 BILLION
DIAMONDS
GEM
INDUSTRIAL
PLATINUM
URANIUM
TUNGSTEN CARBIDE
GOLD
EMERALDS
RHODIUM
IRIDIUM
SILICON MONOCRYSTAL
PALLADIUM
GERMANIUM
SILICON POLYCRYSTAL
BERYLLIUM
QUARTZ CRYSTAL

Fig. 3

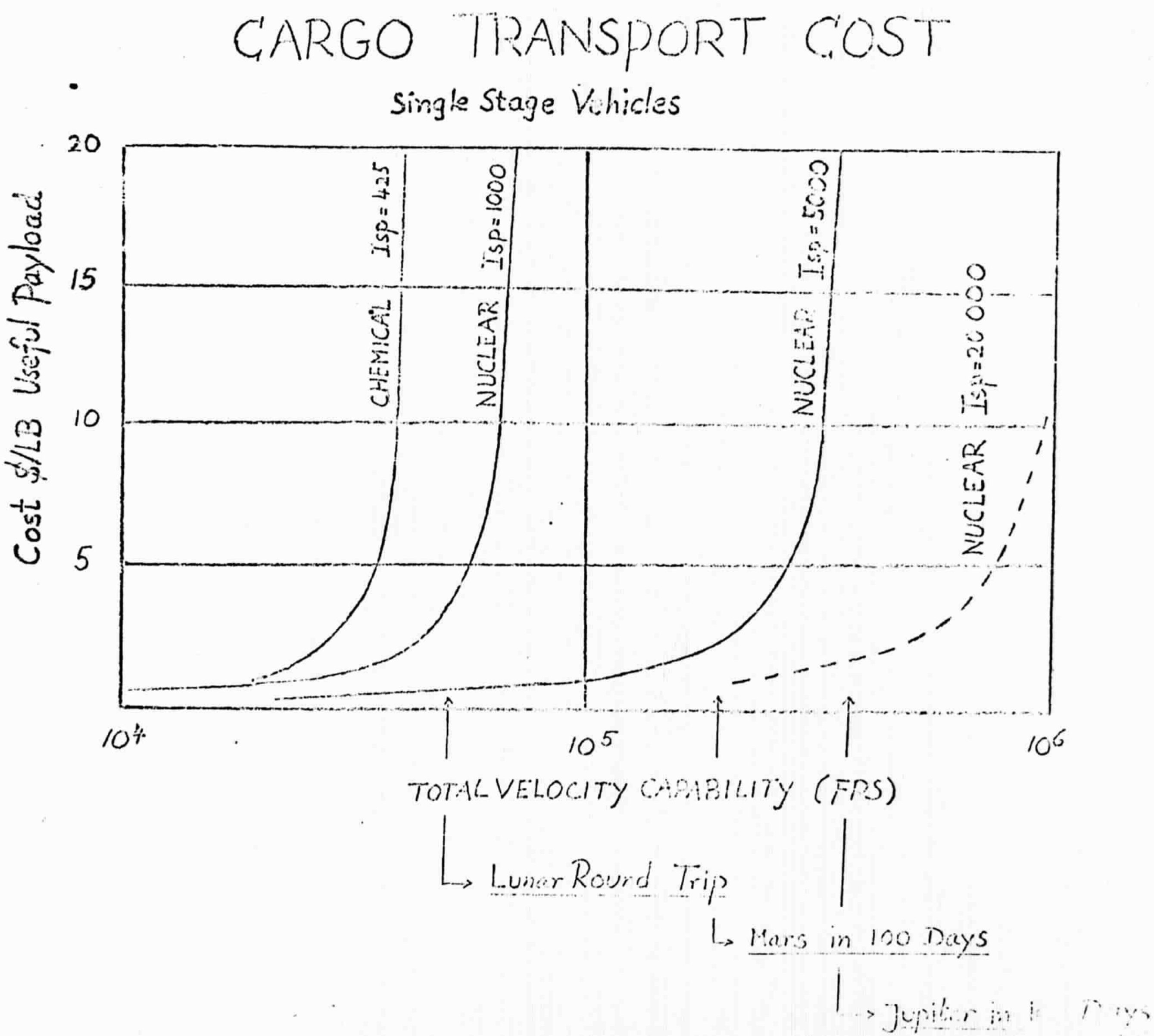

CARGO TRANSPORT COST
Single Stage Vehicles
Cost $/LB Useful Payload
20
15
10
5
CHEMICAL Isp = 425
NUCLEAR Isp = 1000
NUCLEAR Isp = 5000
NUCLEAR Isp = 20 000
10⁴
10⁵
10⁶
TOTAL VELOCITY CAPABILITY (FPS)
Lunar Round Trip
Mars in 100 Days
Jupiter in

Fig. 4

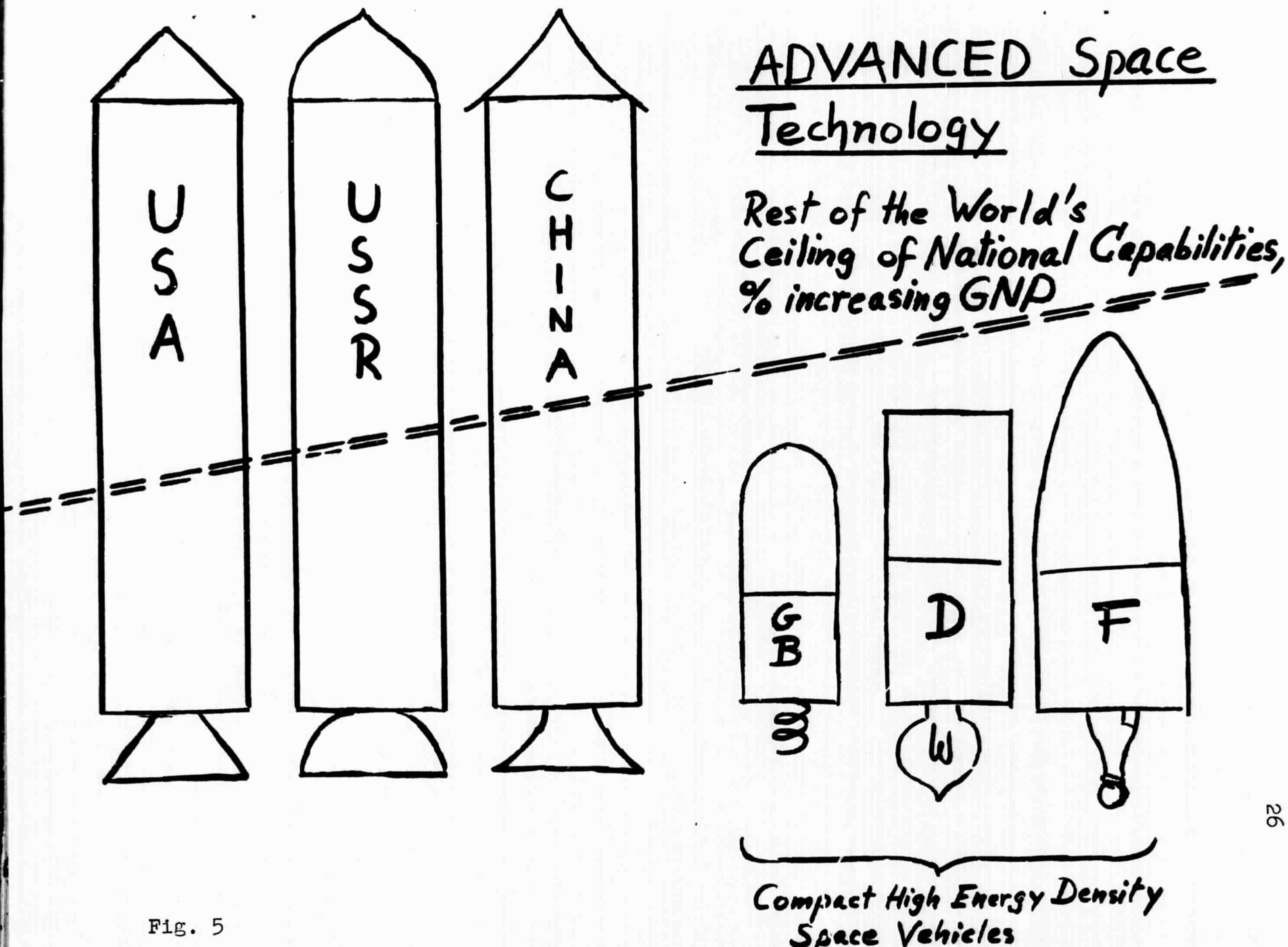
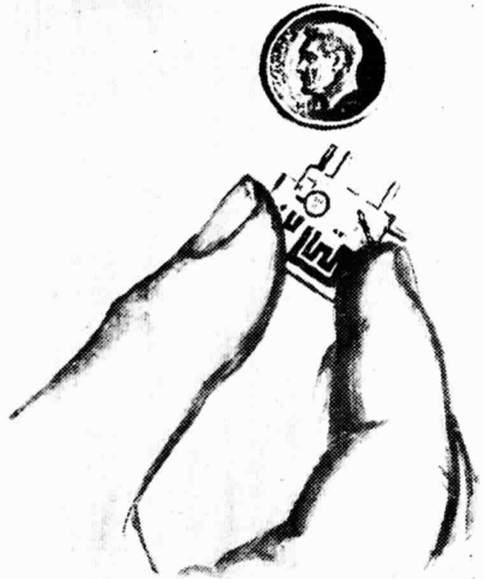

ADVANCED Space Technology
Rest of the World's Ceiling of National Capabilities, % increasing GNP
USA
USSR
CHINA
GB
D
W
F
Compact High Energy Density Space Vehicles

Fig. 5

ADVANCED MICROELECTRIC DEVICES



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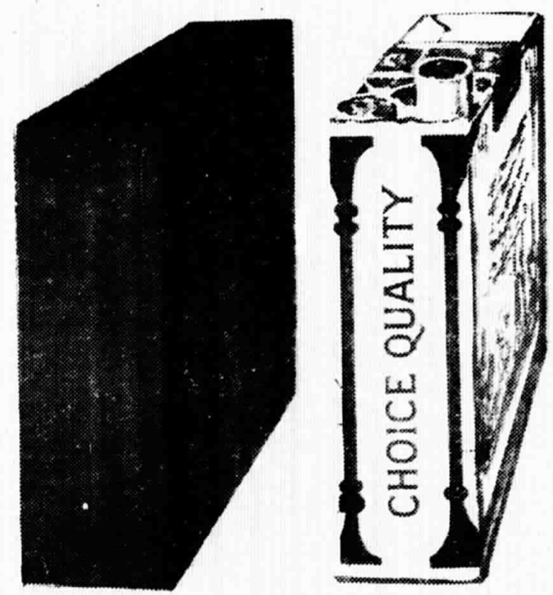


TYPICAL MICROELECTRONIC
THIN FILM DEVICE

- RELIABLE
- RADIATION RESISTANT
- SMALL
- LIGHT

CONVENTIONAL TRANSISTOR
ELECTRONICS

NASA R63-3

Fig. 6

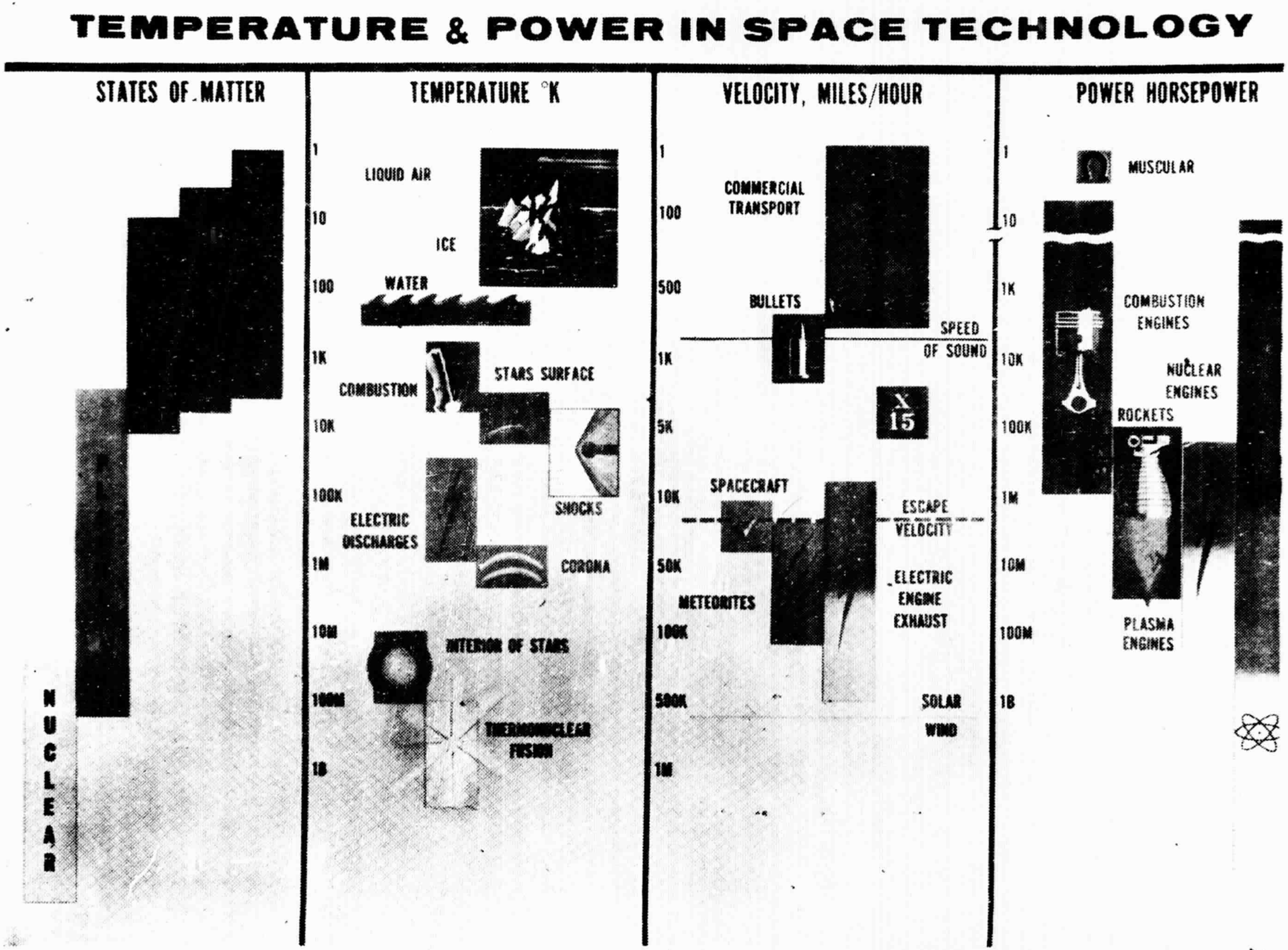
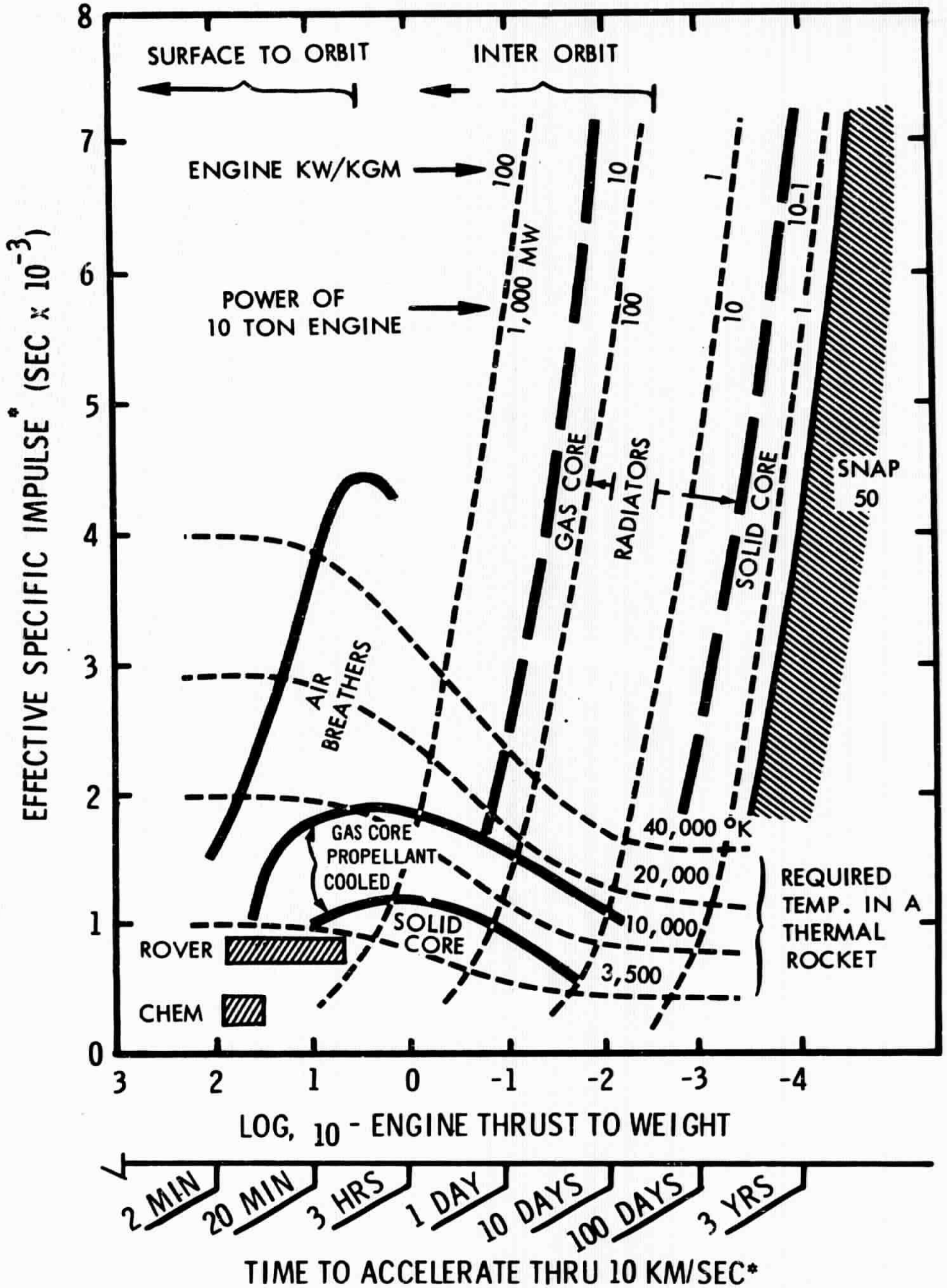

TEMPERATURE & POWER IN SPACE TECHNOLOGY
STATES OF MATTER
NUCLEAR
TEMPERATURE °K
1
10
100
1K
10K
100K
1M
10M
100M
1B
LIQUID AIR
ICE
WATER
COMBUSTION
STARS SURFACE
SHOCKS
ELECTRIC DISCHARGES
CORONA
INTERIOR OF STARS
THERMONUCLEAR FUSION
VELOCITY, MILES/HOUR
1
100
500
1K
5K
10K
50K
100K
500K
1M
COMMERCIAL TRANSPORT
BULLETS
SPEED OF SOUND
X 15
SPACECRAFT
ESCAPE VELOCITY
METEORITES
ELECTRIC ENGINE EXHAUST
SOLAR WIND
POWER HORSEPOWER
1
10
1K
10K
100K
1M
10M
100M
1B
MUSCULAR
COMBUSTION ENGINES
NUCLEAR ENGINES
ROCKETS
PLASMA ENGINES

Fig. 7



* VEHICLE WEIGHT ASSUMED = 10 x ENGINE WEIGHT

Fig. 8